Comparison of Tomographic and Forward Modeling 3D Reconstructions of a Coronal Streamer

Jeffrey Newmark, J. Cook: Naval Research Laboratory
(202) 767-0244, newmark@nrl.navy.mil

P. Reiser: Interferometrics; A. Yahil: Pixon LLC

A. Thernisien: Universities Space Research Association

White Light Reconstruction

- **Strategy: Apply 3D tomographic electron density reconstruction techniques to solar features from low corona through heliosphere to 1 AU. Utilize Brightness, polarized brightness, temporal, 2D white light coronagraph images and synthetic models from 2/3 vantage points, construct (time dependent) 3D electron density distribution.**
- **Focus: Use theoretical CME models and existing LASCO observations prior to STEREO launch in order to predict the range of conditions and features where reconstruction techniques will be applicable.**
- **Goal: Provide a practical tool that will achieve ~daily CME 3D electron density models during the STEREO mission.**
- **Study realistic complexities: Input Synthetic Models -> density structures (uniform vs. cavity vs. “realistic”), K/F corona, time dependence**

Key Aspects

- Renderer - Physics (Thomson scattering), tangential and radial polarization brightness, total brightness, finite viewer geometry, optically thin plasma.
- Reconstruction Algorithm - PIXON (Pixon LLC), Pina, Puetter, Yahil (1993, 1995) - based upon minimum complexity, non-parametric, locally adaptive, iterative image reconstruction. Roughly analogous to multiscale (wavelet) methods (not as closely related to maximum entropy).
  - chosen for speed (large # voxels, up to 10^9): small number of iterations, intelligent guidance to declining complexity per iteration.
  - Minimum complexity: With this underdetermined problem, we make minimal assumptions in order to progress.
- Visualization - 3D electron density distribution, time dependent (movies), multiple instrument, multiple spacecraft, physics MHD models.

3-D Reconstruction Using the NRLPixon Method

- **The problem is to invert the integral equation with noise:**

$$D_n(\mathbf{x}) = \int \mathbf{d}^3\mathbf{r} H_n(\mathbf{x},\mathbf{r}) n(\mathbf{r}) + N_n(\mathbf{x})$$

- **But there are many more model voxels than data pixels.**
- **And the reconstruction significantly amplifies the noise.**
- **All reconstruction methods try to overcome these problems by restricting the model; they differ in how they do that.**
- **A good first restriction is non-negative n(r).**

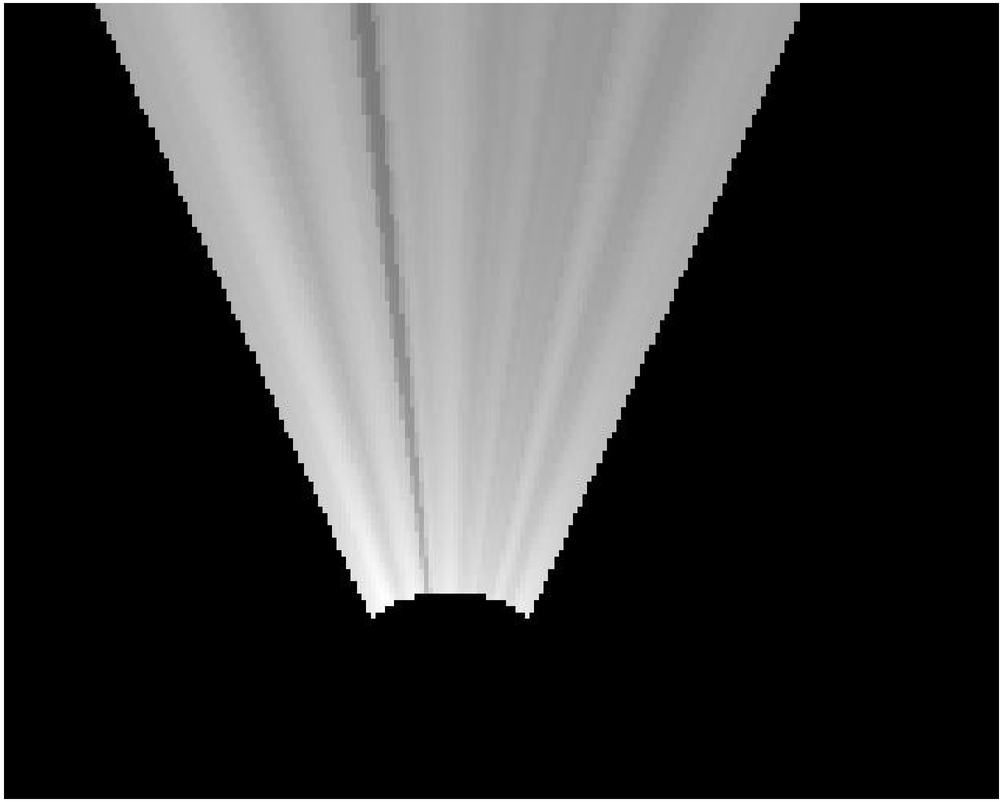
  ⇒ Non-Negative Least-Squares (NNLS) fit.
- **Minimum complexity (Ockham's razor): restrict n(r) by minimizing the number of parameters used to define it.**
- **The number of possible parameter combinations is large.**

  ⇒ An exhaustive parameter search is not possible.
- **The Pixon method is an efficient iterative procedure that approximates minimum complexity by finding the smoothest solution that fits the data (details: Puetter and Yahil 1999).**
- **Adaptive (Hierarchical) Gridding**

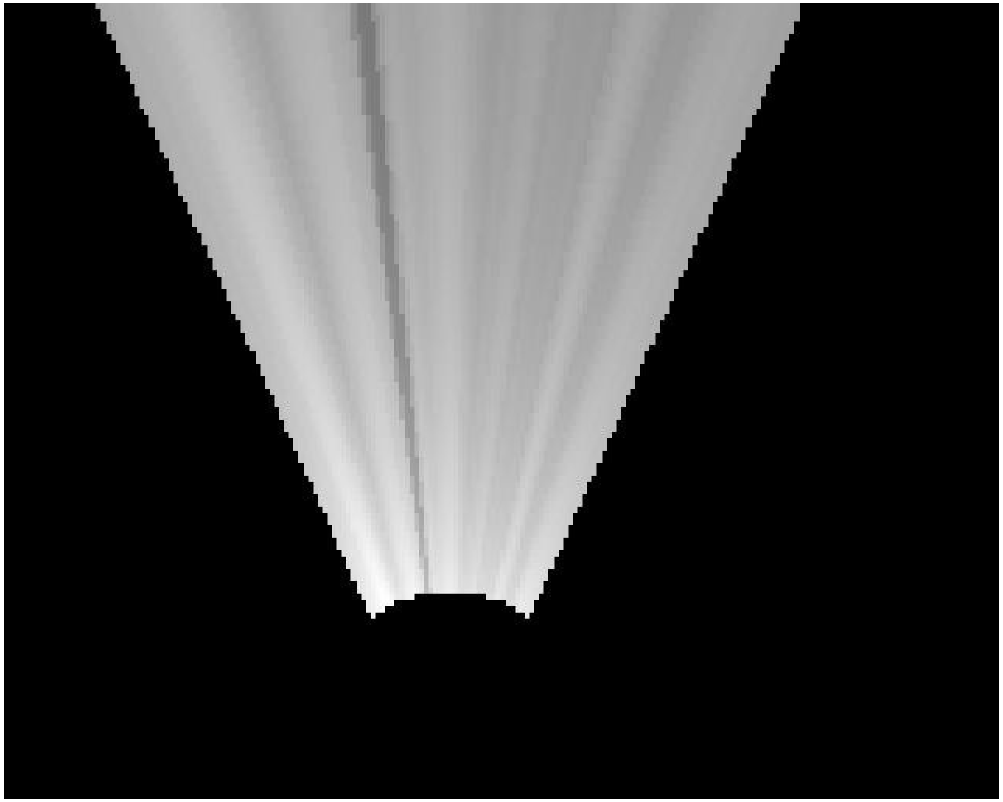
Coronal Streamer – SOHO LASCO

- Compare 3D reconstructions using tomographic and forward modeling techniques – examine rendered (synthetic) data from density as compared to input LASCO data
- Electron Density Forward Modeling: volume constrained, slab model, ad hoc folds (Thernisien et al. 2004, B.A.A.S., 36, 797) – optimize parameters to fit specific functional form
- Comparisons: two steps
  - Verification of tomographic reconstruction – apply to output of forward model
  - Tomographic reconstruction of LASCO data

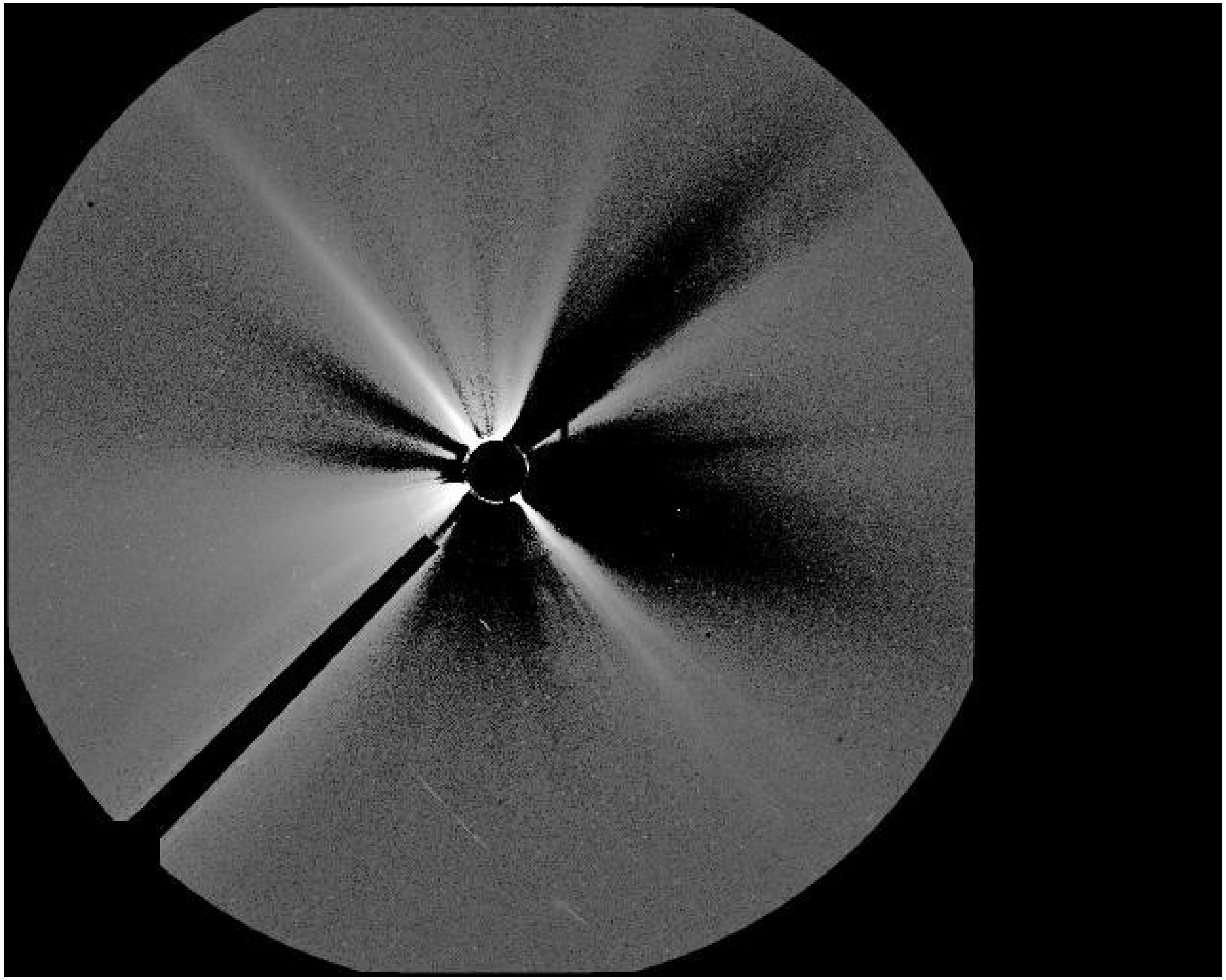
LASCO C3 Data & Forward Model



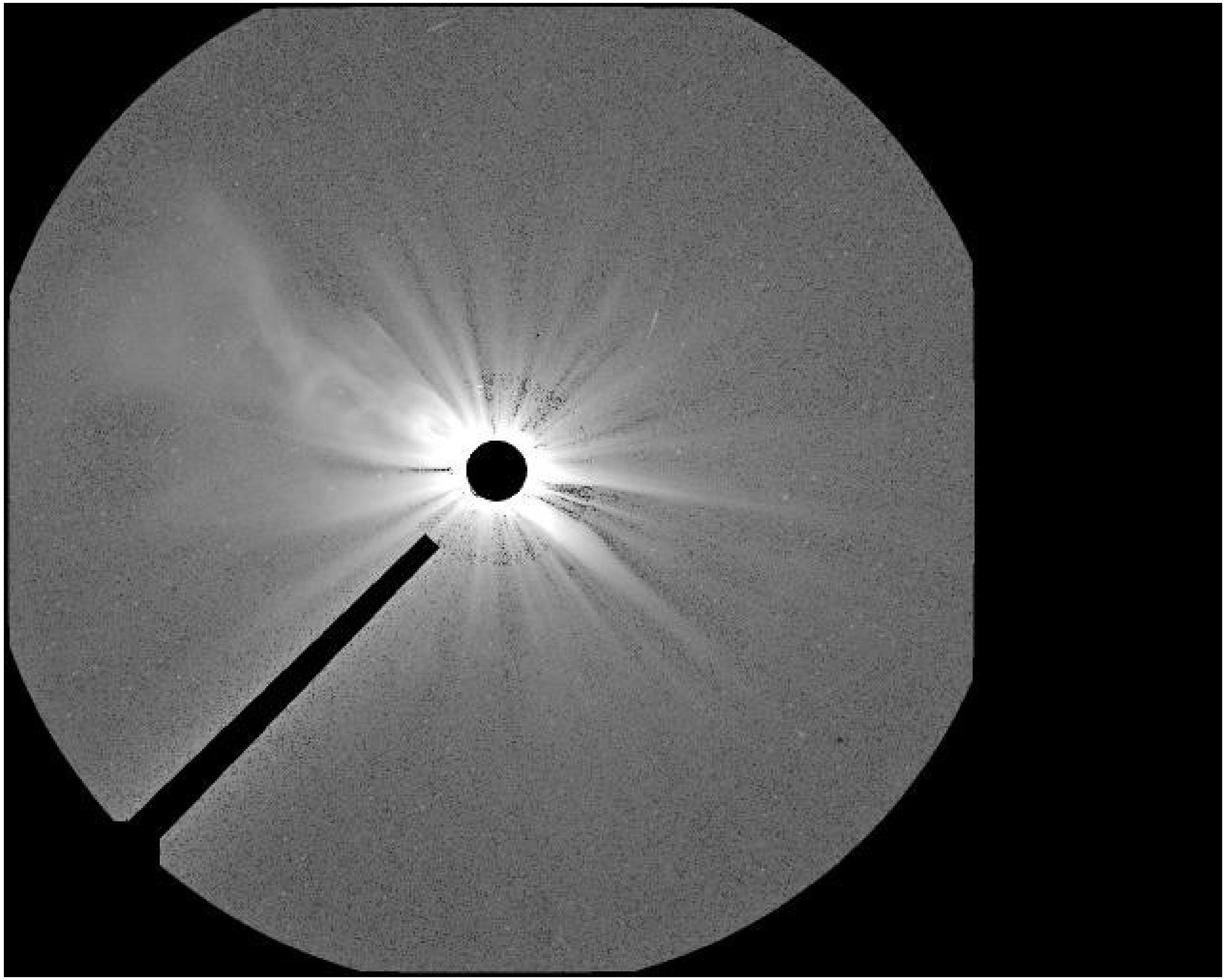
NRLPIXON Reconstruction of Model



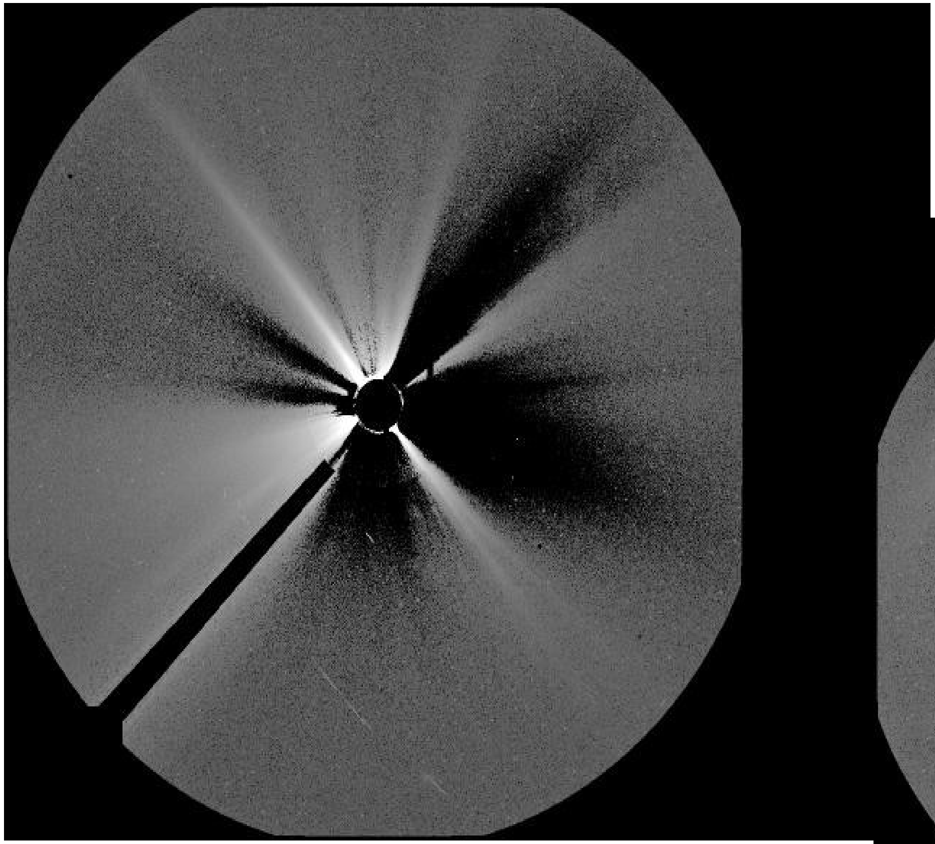
NRLPIXON Reconstruction of LASCO

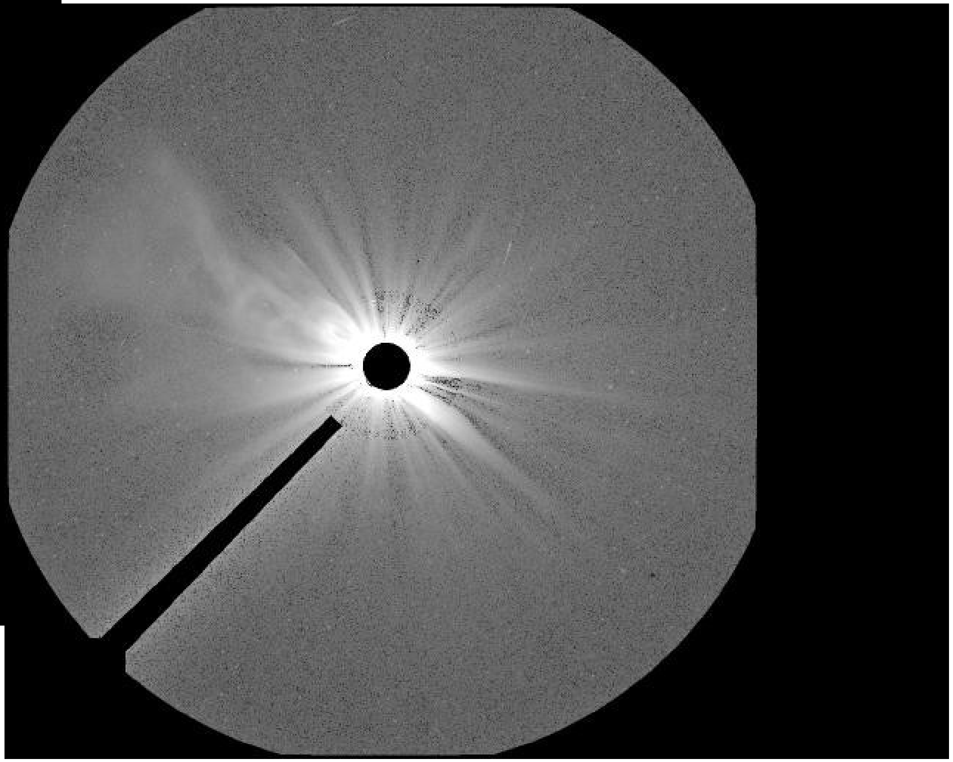


Comparison Data: C3, Model, NRLPIXON



Comparison IMAGE: Forward, NRLPIXON





Analysis

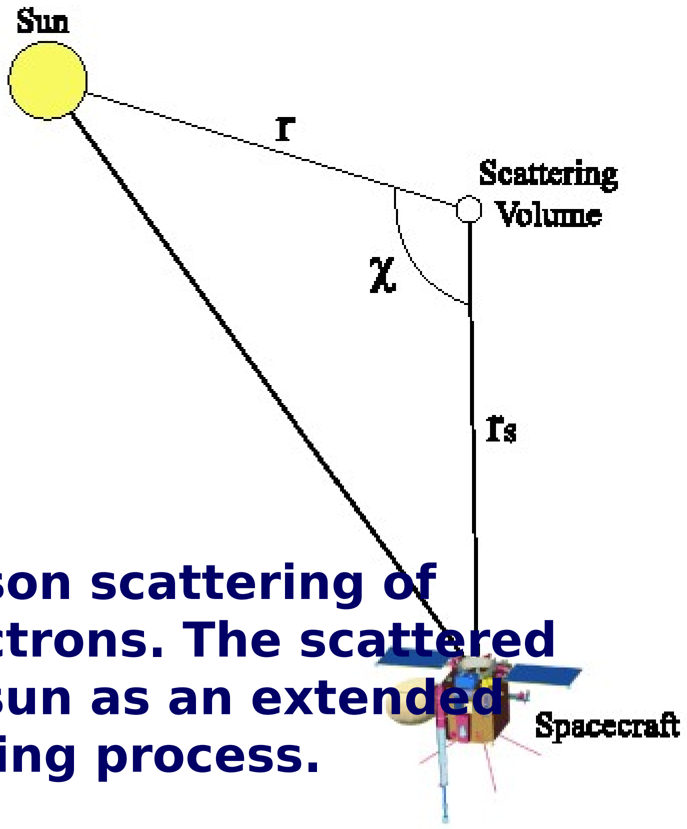
- Tomography from limited viewpoints
- Rotational tomography of model vs. real data

Conclusions

- **Tomographic reconstructions more closely match input data than highly structured and constrained forward modeling approach**
- **Two techniques are complementary – forward modeling investigates the physics while tomography better reproduces the 3D distributions**
- **Continue investigating range of density structures vs. signal-to-noise.**
- **Time dependent reconstructions**
- **Visualization Techniques: 3D from any angle, coordination with 2D observations by SECCHI from both spacecraft, coordination with other STEREO observations, e.g. particles and fields experiments (IMPACT, SWAVES, PLASTIC), coordination with MHD models, coordination with ground-based magnetograms.**
- **Web Site: http://stereo.nrl.navy.mil/ (follow link to 3D R&V).**

BACKUP SLIDES

K-Corona Physics: Thomson Scattering



K-corona arises from Thomson scattering of Photons by hot coronal electrons. The scattered radiation is polarized. The sun as an extended source modifies the scattering process.

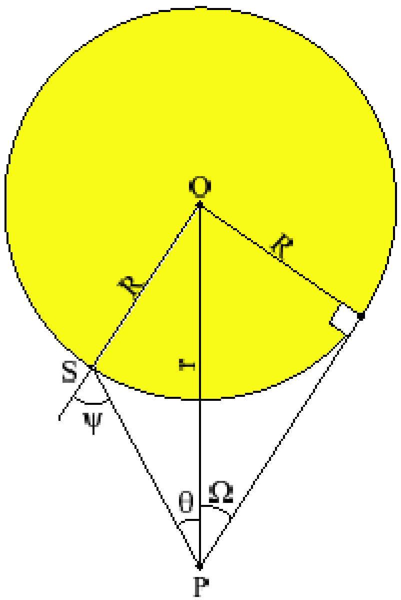
K-Corona Physics: Emission Coefficients

Separate scattered radiation into tange
and radially polarized light. The tangen
emission coefficient (ph s^{-1} cm^{-3} sr^{-1}) m
written as:

$$\epsilon_t(r) = \frac{\pi I_0 \sigma}{2}\, n_e(r)\, \Sigma_A$$

And the radial emission coefficient is:

$$\epsilon_r(r) = \frac{\pi I_0 \sigma}{2}\, n_e(r)\, \left(\Sigma_B\, \cos^2(\chi_s) + \Sigma_C\right)$$



Where we explicitly account for extended sun limb darkening

PIXON: Adaptive (Hierarchical) Gridding

- **Naïve voxel size at the resolution of the projected detector pixels results in 10^9 voxels.**
- **This is computationally unmanageable (or at least very time consuming).**
- **The number of voxels greatly exceeds the number of independent data points, which is only $4x10^6$.**
- **We propose to solve both problems by using a hierarchical 3-D grid, which is coarse where the (projected) data show** n(r) **to be smooth and is progressively refined where the data require** n(r) **to be more structured.**
- **While the Pixon method does not require an adaptive grid, it can take advantage of it in imposing maximum smoothness to increase computational speed by a more efficient calculation.**